EGR 8306 Nonlinear Dynamics

What is this class about?

The dynamics of systems from areas as diverse as mechanical, electrical, fluid, biological, chemical and financial, are generally described by nonlinear models. All these systems exhibit complex phenomena that cannot be understood from linearized mathematical models which are often used in practical engineering. These complex fascinating phenomena such as bifurcations, instabilities, and chaos are often observed and cannot be ignored. Moreover, they are impossible to predict even qualitatively using linearized models.

This course is an introduction to the broad area of nonlinear dynamics. We will use both analytical and computational techniques in order to provide a unified treatment. We will mostly focus on systems governed by ordinary differential equations. Numerous practical applications will be explored.

The emphasis in the course is on applications and interesting nonlinear phenomena in diverse systems. We will not attempt to derive all models (although some background will be provided by the instructor). Examples of systems we looked at last year are as follows.

- Population logistics, rabbits vs. foxes
- Autocatalysis, butterfly wing pattern formations
- Tumor growth, epidemics, insect outbreaks
- Lasers, superconductors
- Beads on wires, pendulums, skydivers, glides
- Leaky buckets, water wheels
- Fluid patterns, B-Z chemical reactions
- Fireflies, cell division
- Geomagnetic reversals
- Lorenz equation, weather predictability
- Dynamics of love and romance
- Economic systems

Sure they all look very different! But we will show in the class how they are all related by the same mathematics of nonlinear dynamics.

Who can take it?

Graduate students in Engineering, Physics or Mathematics; undergraduate senior students with permission.

Prerequisites

Knowledge of ODEs, matrix theory, computational ability (MATLAB preferred).

For more information please contact Dr. Nat at nataraj@villanova.edu.

EGR 8306 Nonlinear Dynamics

Term:	Spring 2017
Instructor:	Dr. "Nat" C. Nataraj
Classes:	Thursdays, 6:15-9:00, CEER 109
Office:	Tolentine 126C, 610-519-4994
Office Hours:	By appointment
E-mail:	nataraj@villanova.edu (for general questions), nondyn.villanova@gmail.com (for all submissions)
Web page:	http://www.homepage.villanova.edu/c.nataraj/

Course Description

The dynamics of systems as diverse as from the areas of mechanical, electrical, fluid, biological, chemical and financial, are generally described by nonlinear models. All these systems exhibit complex phenomena that cannot be understood from linearized mathematical models which are often used in practical engineering. These complex phenomena such as bifurcations, instabilities, and chaos are often observed and cannot be ignored. Moreover, they are fascinating and impossible to predict using linearized models.

This course is an introduction to the broad area of nonlinear dynamics. We will use both analytical and computational techniques in order to provide a unified treatment. We will mostly focus on systems governed by ordinary differential equations but briefly touch upon difference equations and partial differential equations as well. Numerous practical applications will be explored.

Prerequisites/Co-requisites

Graduate engineering mathematics and an exposure to computer programming is expected. All students are **required** to use MATLAB, an interactive scientific software which can be used for numerical analysis, matrix computation, and graphics. If time permits, we will also use AUTO, a computer tool for bifurcation analyses.

Minimum Course Expectations

To be successful in this course, the students must at a minimum do the following.

- Attend all classes or get material missed if absent. It is important to attend class and to arrive on time to class. Important information including homework assignments, exam announcements and policy changes may be announced in class. You are re-

sponsible for all course information and lateness or absence does not excuse you from compliance. Students may not assume that all course announcements will be emailed.

- Contact the instructor during office hours with any questions or uncertainties.
- Complete all assignments on time and according to directions.

Attendance Policy

It is strongly recommended that the students attend all the class sessions. It is imperative that the students participate actively in the class sessions by asking and answering questions. Continual absences will result in a 10% penalty in the final grades.

Students are responsible for all material covered during class (which may include information not in the book) and all assignments with no exceptions.

Contact

Please feel free to contact me through e-mail (nataraj@villanova.edu). If you need to send any submissions (such as homework) please use nondyn.villanova@gmail.com; please do not copy or use my Villanova account for big files. In general, I don't check my gmail account, so for quick questions please use the Villanova account. **IMPORTANT: in all cases, please type "Nonlinear Dynamics" in the subject line.**

Text

Required: Strogatz, S. H., 2014, "Nonlinear Dynamics & Chaos," Westview Press, Second Edition. ISBN 978-0813349107. This is a delightful book almost suitable for self-study. You may also want to get the student solution manual. Note that the Kindle edition may have some issues with the typesetting of equations; I would recommend the Carbon variety.

Other References:

1. E. Atlee Jackson, 1991, "Perspectives of Nonlinear Dynamics: Volumes 1 and 2," Cambridge Press.
2. Brauer, F., and Nohel, J. A., 1969, "The qualitative theory of ordinary differential equations," Dover Publications.
3. Butenin, N. V., 1965, "Elements of the theory of nonlinear oscillations," Blaisdell Publishing Company.
4. Coddington, E. A., and Levinson, N., 1955, "Theory of Ordinary Differential Equations," McGraw-Hill.

5. Gilmore, R., 1981, "Catastrophe theory for scientists and engineers," Dover Publications.

6. Hale, Jack K., 1963, "Oscillations in nonlinear systems," Dover Publications.

7. Robert Hilborn, 2001, "Chaos and Nonlinear Dynamics: An Introduction for Scientists and Engineers," Oxford University Press.

8. Nayfeh, A. H., & Mook, 1979, "Nonlinear Oscillations."

9. Nayfeh, A. H., 1981, "Introduction to Perturbation Techniques," John Wiley & Sons.

10. Nayfeh, A. H. and Balachandran, B., 1995, "Applied Nonlinear Dynamics," Wiley-CVCH, ISBN 978-0-471-59348-5. This is a traditional text book / monograph.

11. Struble, R. A., 1962, "Nonlinear Differential Equations," McGraw-Hill.

12. Nataraj, C., Research Notes.

13. Numerous technical publications.

The Strogratz text is more at the senior undergraduate level. I intend to work out some very interesting examples from Strogartz. You will also get reading assignments from Strogratz. I will take some material from Nayfeh's texts, other books, and my own research notes.

There may be additional reference material in the form of research papers; they will be handed out to you.

Grading:

Homework will be assigned every week and should be submitted promptly for grading and subsequent discussion. In addition, small computer projects will be assigned.

An individual term project will be required of each student. The project topic may be either selected by the student, with approval, or be specified by the instructor. It is initiated at the mid-term date and is due in the last class week; a presentation will be required.

The semester grade is based on the following relative weights.

Homework	15%
Tests (two/three)	30%
Computer project(s)	30%
Final Exam (comprehensive)	25%

I reserve the right to change the number and/or type of assignments and the method of calculating the grade. Be assured that I will do so in a reasonable fashion and for logical and pedagogical reasons!

Grades:

F < 65% C- < 70% < C < 75% < C+ < 80%< B- < 82% < B < 85% < B+ < 87% < A- < 90% < A

Other Issues

Academic Integrity All assignments must be in accordance with the Villanova Code of Academic Conduct. Violations of the code of Academic Integrity and will be dealt with appropriately by the office of the Vice President for Academic Affairs. Responsibility for maintaining the code of academic integrity does not rest solely with the faculty. It is the responsibility of students to report violations to the code of academic integrity to the instructor.

It is the fervent hope of this instructor that the students come to this class motivated to learn the material. A final grade is only a partial reward; the real reward should be the understanding and intellectual stimulation I hope to instil in each of you. Hence, any cheating would be self-defeating. I am not responsible for policing and do not want to be diverted from my essential mission of teaching. However, if I discover any cheating I am required by university policy to report all instances to the VPAA; and the penalties are pretty severe. At that point, it will be out of my hands; please don't put me in that position.

Please see the last two pages for the Engineer's Code of Ethics.

Disabilities It is the policy of Villanova to make reasonable academic accommodations for qualified individuals with disabilities. If you are a person with a disability please contact me after class or during office hours and make arrangements to register with the Learning Support Office by contacting 610-519-5636 or at nancy.mott@villanova.edu as soon as possible. Registration with the Learning Support Office is required in order to receive accommodations.

Course Syllabus

Simple pendulum example; Review of linear system theory; linearization, stability, numerical solutions; Phase plane analysis and Poincaré maps; Stability concepts; Periodic solutions; Jump phenomena; parametric excitation; Asymptotic methods; multiple scales and averaging; Floquet theory; Bifurcation theory; Chaotic oscillations; numerical tools; Complex systems.

National Society of Professional Engineers®

Code of Ethics for Engineers

Preamble

Engineering is an important and learned profession. As members of this profession, engineers are expected to exhibit the highest standards of honesty and integrity. Engineering has a direct and vital impact on the quality of life for all people. Accordingly, the services provided by engineers require honesty, impartiality, fairness, and equity, and must be dedicated to the protection of the public health, safety, and welfare. Engineers must perform under a standard of professional behavior that requires adherence to the highest principles of ethical conduct.

I. Fundamental Canons

Engineers, in the fulfillment of their professional duties, shall:

1. Hold paramount the safety, health, and welfare of the public.
2. Perform services only in areas of their competence.
3. Issue public statements only in an objective and truthful manner.
4. Act for each employer or client as faithful agents or trustees.
5. Avoid deceptive acts.
6. Conduct themselves honorably, responsibly, ethically, and lawfully so as to enhance the honor, reputation, and usefulness of the profession.

II. Rules of Practice

1. Engineers shall hold paramount the safety, health, and welfare of the public.
   a. If engineers' judgment is overruled under circumstances that endanger life or property, they shall notify their employer or client and such other authority as may be appropriate.
   b. Engineers shall approve only those engineering documents that are in conformity with applicable standards.
   c. Engineers shall not reveal facts, data, or information without the prior consent of the client or employer except as authorized or required by law or this Code.
   d. Engineers shall not permit the use of their name or associate in business ventures with any person or firm that they believe is engaged in fraudulent or dishonest enterprise.
   e. Engineers shall not aid or abet the unlawful practice of engineering by a person or firm.
   f. Engineers having knowledge of any alleged violation of this Code shall report thereon to appropriate professional bodies and, when relevant, also to public authorities, and cooperate with the proper authorities in furnishing such information or assistance as may be required.
2. Engineers shall perform services only in the areas of their competence.
   a. Engineers shall undertake assignments only when qualified by education or experience in the specific technical fields involved.
   b. Engineers shall not affix their signatures to any plans or documents dealing with subject matter in which they lack competence, nor to any plan or document not prepared under their direction and control.
   c. Engineers may accept assignments and assume responsibility for coordination of an entire project and sign and seal the engineering documents for the entire project, provided that each technical segment is signed and sealed only by the qualified engineers who prepared the segment.
3. Engineers shall issue public statements only in an objective and truthful manner.
   a. Engineers shall be objective and truthful in professional reports, statements, or testimony. They shall include all relevant and pertinent information in such reports, statements, or testimony, which should bear the date indicating when it was current.
   b. Engineers may express publicly technical opinions that are founded upon knowledge of the facts and competence in the subject matter.
   c. Engineers shall issue no statements, criticisms, or arguments on technical matters that are inspired or paid for by interested parties, unless they have prefaced their comments by explicitly identifying the interested parties on whose behalf they are speaking, and by revealing the existence of any interest the engineers may have in the matters.
4. Engineers shall act for each employer or client as faithful agents or trustees.
   a. Engineers shall disclose all known or potential conflicts of interest that could influence or appear to influence their judgment or the quality of their services.
   b. Engineers shall not accept compensation, financial or otherwise, from more than one party for services on the same project, or for services pertaining to the same project, unless the circumstances are fully disclosed and agreed to by all interested parties.
   c. Engineers shall not solicit or accept financial or other valuable consideration, directly or indirectly, from outside agents in connection with the work for which they are responsible.
   d. Engineers in public service as members, advisors, or employees of a governmental or quasi-governmental body or department shall not participate in decisions with respect to services solicited or provided by them or their organizations in private or public engineering practice.
   e. Engineers shall not solicit or accept a contract from a governmental body on which a principal or officer of their organization serves as a member.
5. Engineers shall avoid deceptive acts.
   a. Engineers shall not falsify their qualifications or permit misrepresentation of their or their associates' qualifications. They shall not misrepresent or exaggerate their responsibility in or for the subject matter of prior assignments. Brochures or other presentations incident to the solicitation of employment shall not misrepresent pertinent facts concerning employers, employees, associates, joint venturers, or past accomplishments.
   b. Engineers shall not offer, give, solicit, or receive, either directly or indirectly, any contribution to influence the award of a contract by public authority, or which may be reasonably construed by the public as having the effect or intent of influencing the awarding of a contract. They shall not offer any gift or other valuable consideration in order to secure work. They shall not pay a commission, percentage, or brokerage fee in order to secure work, except to a bona fide employee or bona fide established commercial or marketing agencies retained by them.

III. Professional Obligations

1. Engineers shall be guided in all their relations by the highest standards of honesty and integrity.
   a. Engineers shall acknowledge their errors and shall not distort or alter the facts.
   b. Engineers shall advise their clients or employers when they believe a project will not be successful.
   c. Engineers shall not accept outside employment to the detriment of their regular work or interest. Before accepting any outside engineering employment, they will notify their employers.
   d. Engineers shall not attempt to attract an engineer from another employer by false or misleading pretenses.
   e. Engineers shall not promote their own interest at the expense of the dignity and integrity of the profession.
2. Engineers shall at all times strive to serve the public interest.
   a. Engineers are encouraged to participate in civic affairs; career guidance for youths; and work for the advancement of the safety, health, and well-being of their community.
   b. Engineers shall not complete, sign, or seal plans and/or specifications that are not in conformity with applicable engineering standards. If the client or employer insists on such unprofessional conduct, they shall notify the proper authorities and withdraw from further service on the project.
   c. Engineers are encouraged to extend public knowledge and appreciation of engineering and its achievements.
   d. Engineers are encouraged to adhere to the principles of sustainable development[1] in order to protect the environment for future generations.